Receding and disparity cues aid relaxation of accommodation

Article

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Abstract: Purpose
Accommodation can mask hyperopia and reduce the accuracy of non-cycloplegic refraction. It is therefore important to minimize accommodation to obtain as accurate a measure of hyperopia as possible. In order to characterize the parameters required to measure the maximally hyperopic error using photorefraction, we used different target types and distances to determine which target was most likely to maximally relax accommodation and thus more accurately detect hyperopia in an individual.
Methods
A PlusoptiX SO4 infra-red photorefractor mounted in a remote haploscope presented the targets. All participants were tested with targets at four fixation distances between 0.3m and 2m containing all combinations blur, disparity and proximity/looming cues. 38 infants (6-44 wks) were studied longitudinally, and 104 children (4 -15 yrs (mean 6.4yrs)) and 85 young adults, with a range of refractive errors and binocular vision status, were tested once. Cycloplegic refraction data was available for a sub-set of 59 participants spread across the age range.
Results
The maximally hyperopic refraction (MHR) found at any time in the session was most frequently found when fixating the most distant targets and those containing disparity and proximity/looming cues. Presence or absence of blur was less significant, and targets in which only single cues to depth were present were also less likely to produce MHR. MHR correlated closely with cycloplegic refraction (r = 0.93,mean difference 0.07D,p=n.s.,95%CI ±<0.25D) after correction by a calibration factor.
Conclusion
Maximum relaxation of accommodation occurred for binocular targets receding into the distance. We suggest that proximal and disparity cues aid relaxation of accommodation to a greater extent than blur, and thus non-cycloplegic autorefraction targets should incorporate these cues. This is especially important in screening contexts with a brief opportunity to test for significant hyperopia. MHR in our laboratory was found to be a reliable estimation of MSE by cycloplegic refraction.

Title Page

Receding and disparity cues aid relaxation of accommodation

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*Abstract

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Key Words

Accommodation cues hyperopia photorefraction infant

The motivation for this study was to determine how best to estimate maximally hyperopic spherical refraction (MHR) using non-cycloplegic photorefraction. In our laboratory this is particularly important for our research into the development of accommodation, since many infants and children are known to be hyperopic, and this hyperopia may not only change rapidly in infancy [1, 2] but also is likely to influence accommodation responses. Cycloplegic refraction gives a “gold standard” measure of refractive error in children, but cycloplegic refraction is not practicable with frequently repeated sessions and is ethically questionable in typically developing children, so we were keen to ascertain the most accurate non-cycloplegic estimate of refraction.

Outside the research context, it is not practicable to use cycloplegic refraction in large-scale screening situations, and so non-cycloplegic autorefraction is commonly used for detecting and assessing significant refractive error. It is quick, acceptable to children and can be administered by less highly trained personnel. There is always, however, a risk of underestimation of hyperopia (and over estimation of myopia[3, 4]) if accommodation is active. Recent reports by Dahlman-Noor et al [5, 6] show that the Plusoptix SO4 photoscreener we discuss here, if used alone, may underestimate refractive error and may miss significant clinical problems. Kaakinen and Ranta-Kemppainen [7], using a two-flash method, also reported false negatives, and under-referral of hyperopia, as did Ghose et al using a NR-1000F Auto Refractometer [8]. Hyperopia is, however, arguably the most important refractive error to detect in young children because of its association with strabismus and amblyopia [9-12]. Hyperopia is also reported to be associated with poor progress at school [13,14] and poorer motor skills [15]. It is therefore important to develop screening paradigms which have the best chance of correctly detecting hyperopia, and therefore lead to more hyperopic children receiving prompt correction.

In more general accommodation research it may also be important to open the accommodation loop to study responses. Most methods used are based on the assumption that blur is the main cue to accommodation, so minimizing blur cues will open the loop and help minimize accommodation. Although absence of all visual stimuli leads to intermediate levels of accommodation, such as in the case of dark focus[16], different methods at higher light levels have been found produce responses nearer to those found under cycloplegia. Experimentally, pinholes or difference of Gaussian (DoG) targets [17] can be used, while different commercial autorefractors minimize accommodation by placing the targets at optical infinity, or using non-accommodative targets such as spot lights or LEDs.

In optometric practice, the fogging technique is a common method used to minimize accommodation during refraction [18, 19]. Queiros et al [20] used autorefraction to compare open field accommodative responses with non-fogged viewing, +2.00D fogging lenses, and responses with cycloplegia and found that fogging lenses helped relaxation of monocular accommodation.

In terms of target distance, Suryakumar & Bobier [21] compared different types of autorefractor at the manufacturer’s recommended testing distances and also added a 3.5m DoG target. They found that farther testing distances and a DoG target aided detection of maximum hyperopia.

Many of the above studies only reported results from one eye and some did not specify whether the children were occluded at the time of refraction. We [22], and others [23] have found, in both infants and older subjects, that disparity cues have a large influence on accommodative responses, supporting views for a strong role for vergence accommodation[24-26]. It is therefore possible that disparity also plays a role in the relaxation, as well as the exercise of accommodation. Proximal / looming cues may also have a role, especially in early infancy where not only may disparity detection be immature but blur cues also be unreliable due to poor acuity [27] or the high prevalence of refractive errors [1].

Although there have been reports comparing different photoscreening methods [28-31] and others comparing accommodative responses to some of the techniques commonly used to relax accommodation[18-20], there have been no reports specifically addressing a wide spectrum of target types during autorefraction in a within-subjects design with a range of participants and age-groups.

Our laboratory has been investigating accommodation and vergence responses to different combinations of the three main near cues of disparity, blur and proximity/looming using an autorefraction technique in a large group of participants from infancy to adulthood. We have used this dataset to establish the target type that maximizes hyperopic refraction within a testing session and have compared this estimate of refraction (mean spherical equivalent (MSE)) to that obtained from a "gold standard" cycloplegic retinoscopy in a subsample of participants. We have considered whether increasing target distance beyond 1 meter increases accuracy and whether statistical differences are large enough to be clinically significant. We have also examined the data to ascertain whether our findings are applicable across the age span. If we can demonstrate that they are, our findings may also help to improve accuracy of photoscreening and refraction in a wider context.

Methods

All studies adhered to the tenets of the Declaration of Helsinki and were scrutinized by University of Reading and UK National Health Service Ethics Committees. Adults and parents of children under 6 years gave fully informed consent. Parents of children older than 6 years gave fully informed consent and the children themselves gave informed assent appropriate to their age.

Our laboratory uses a remote haploscopic videorefractor (RHV) to measure vergence and accommodation responses in naturalistic conditions. This apparatus has been described in detail elsewhere [22] but is described briefly here. It combines two optical pathways, one for target presentation and manipulation and one for data capture (Figure 1). The participant sees that target approaching and receding in the mid-line, while infra-red photorefraction occurs in the same plane independent of target position.

…………………………Figure 1 …………………………………………………………….

Photorefraction Pathway

We use a commercially available infra-red photorefractor (PlusoptiX S04, Plusoptix GmbH, Nurenberg, Germany). This is primarily marketed and used for child vision screening in the “C-Mode” but also incorporates a PowerRefII (“R-Mode”) that makes simultaneous recordings of accommodative state and gaze direction, which we are using to carry out our more detailed studies. In our laboratory the PlusoptiX S04 captures the image of the participant's eyes via a large 600mm diameter "hot" mirror which reflects infra-red wavelengths but allows through visible light. As we are interested in binocular responses, the camera is mounted in the midline between the eyes. The fixation LEDs on the photorefractor are covered with opaque tape. When no target is presented, the infra-red sources can be seen subjectively as very faint red dots, but when any fixation target is on the target monitor, these are obscured by the brighter target elements and are invisible to the participant.

During the calibration phase of our studies we consistently measured a smaller accommodative response (more hyperopic spherical refraction) to target demand with the RHV in comparison to dynamic retinoscopy, and this increased away from 0 D, as found by Harb et al using an earlier version of the PowerRefractor[32]. We used a correction function of 1.2385x+0.799, where x = accommodation measured by the PowerRefII, to adjust estimates of refraction in our lab.

Target Pathway

The targets are presented on a video monitor mounted on a motorized beam and viewed via two concave mirrors such that the image is placed optically at target positions between 0.25m and 2m from the participant. Targets are presented at five different fixation distances in a pseudo-random order (0.3m, 2m, 0.25m, 1m, 2m), representing 4D-0.5D demand. Data from the 0.25m target was discarded due to the unacceptable loss of data caused by small pupils in many participants, but the target position was retained in the presentation sequence because it meant that a distant target was always presented after a near one and vice versa.

The advantages of the mirror system are that target presentation and photorefraction can occur in the same plane without the sensors obscuring the target, or vice versa, and also that disparity cues can be removed by occluding half of the upper mirror remote from the participant (F in Figure 1), so there is no distracting occluder visible to the participant.

Targets

The same range of targets was used for all participants, designed to maximize or minimize access to blur, disparity and proximity cues separately. Blur cues were made available by using a high contrast brightly colored clown target containing a wide range of spatial frequencies. Blur cues were minimized using a similar sized DoG target against a black background, which has been found to open the accommodation loop [17]. Both targets alternated at 1Hz between two different forms in terms of color (DoG target) and detail (clown target) to maintain attention of the youngest participants. Disparity cues were available when both eyes viewed the target, and eliminated by remote occlusion at the level of the upper mirror. The occlusion is invisible to the participant and even approximately 30% of adults were unaware that they had been monocular at times. Looming / proximity cues were made available by presenting the same size target at each fixation distance and allowing the participant to watch the monitor move between target positions (both the clown and the DoG targets subtended 3.15° at 2m and 18.26° at 33cm). Proximity cues were minimized by scaling the targets so that they subtended the same angular subtense at each fixation distance (3.15°), and also by obscuring the participants' view of the screen with an opaque black cloth screen as it moved between fixation distances so that the target was only uncovered once the monitor had stopped moving and its position could not be guessed from changing size cues.

We were therefore able to present all combinations of the three main cues to vergence and accommodation. Although the monitor and camera are mounted within black painted shuttering, some residual minimal looming and blur cues are still available from the background luminance of the black screen background against the screen edge, despite efforts to mask this with graduated filters, so a "zero" cue condition was also included to assess the impact of residual cues we could not eliminate. Testing order was standardized across all participants and was designed to maximize infant data, where a full testing session with all cue combinations presented might exceed attention span, but where we were particularly interested in the relative use of the different cues. We, and others, have reported that infant attention reduces under monocular conditions [23,33] and we anticipated that removing either of the other two cues could have similar effects, while removing two of the three cues might be even more disruptive. In order to maximize data in infants with limited attention, we chose to present the all-cue (blur, disparity & proximity (*bdp* – binocular, looming, clown)) condition first, followed by a block of the three conditions in which one-cue was removed (*bd* (binocular, scaled clown), *bp*(looming, occluded clown) or *dp* (binocular, looming DoG) with testing order counterbalanced across participants. If attention permitted, we then tested the three conditions in which one cue only was presented (*b* (occluded, scaled clown),*d* (binocular, scaled DoG) or *p* (occluded, looming DoG)), also counterbalanced between participants. A penultimate “zero cue” (occluded, scaled DoG) was presented next, followed by a final all-cue (*bdp)* condition. Repeating the all-cue condition at the end enabled us to assess whether waning attention was due to reducing cues or fatigue. All participants reported here were those who completed testing with all eight target conditions. With all except the youngest infants, testing was repeated within the testing session in a counterbalanced order.

Participants

Participants were recruited from the Infant Database and Psychology Undergraduate Research Panel at the University of Reading, as well as local hospital children’s eye clinic patients and their siblings. As we were interested in providing data that could be used to improve testing in unselected populations we have included all the participants tested in our laboratory who were able to complete testing with the full range of targets. We therefore did not select on the basis of visual acuity, refractive error or binocular status. Any participants showing refractions outside the operating range of the PowerRef II (-7.0D to +5.0D) at any time were excluded.

38 infants were able to provide a full dataset and were seen on between one and nine occasions (mean 3.05 visits) between the ages of 6 and 44 weeks as part of a longitudinal study of typical development. None have subsequently developed strabismus. As refractive error is known to change rapidly throughout early infancy we have included data from repeated testing sessions. 104 children between 4 and 15 years were assessed (mean age 6.4yrs SD±1.9yrs). 52 of these were developing typically with visual acuity of better than 0.2 LogMAR in either eye and no

strabismus. 52 children had a refractive error within the operating range of the PlusoptiX S04 and/or intermittent strabismus. Six had small angle constant strabismus with gross stereopsis on the Titmus stereotest and 33 had intermittent eso- or exotropia with normal binocular vision (60 seconds of arc on the TNO stereotest) when the deviation was controlled. For this study all measurements were carried out without spectacles. We also tested 85 young adults between 19 and 25 years of age. All had had a recent subjective refraction. 59 of the adults did not wear a correction (refraction MSE within 0.75D of emmetropia) and the others had a range of refractive errors and were tested either with their own contact lenses (n=16) or without glasses if worn (n=10).

All non-infant children and adults were tested on only one visit but measurements were repeated within the session to assess for repeatability. As many of our studies are on infant development, we made strenuous efforts to ensure that our older participants were completely naïve to vision experiments and the theory of vision. None of the child or adult participants had been given orthoptic exercises that might have changed their habitual responses to blur or disparity cues.

Of this large group of infants and children, we were able to obtain recent cycloplegic refraction data on 59 participants. This testing was carried out 40 minutes after using 2 drops of cyclopentolate hydrochloride 1% in each eye, within 3 months of testing in the laboratory for the children and within one month for the infants (17 of which were infants at 26 weeks) who might be emmetropizing more rapidly.

Analysis

Data was recorded and analyzed initially using Excel. Statistical analyses were carried out using SPSS 14.

Results

Data were available from 316 testing sessions with 227 participants. Because of the testing sequence used, all targets were tested at least once, but the *bdp* target was tested at the beginning and end of testing. Examination of repeated data (*bdp* at the start and end of each testing sequence, and repetition of all targets in a counterbalanced order if co-operation allowed) showed no significant differences in accommodation responses between testing early or late in the sequence ($p>0.4$ in all comparisons), i.e. there were no fatigue or practice effects.

For each participant, the target which produced the maximally hyperopic refraction during the session was determined. Figure 2 shows the percentage of MHR found for each target condition. There was a significant difference in the distribution of the MHR across targets ($\chi^2= 110.0$, df 7, $p<0.00001$). MHR was most frequently found when using the *bdp* (binocular, looming clown) and *dp* (binocular, looming DoG) targets. These two target conditions together contributed 49.8% of all maximum hyperopia / minimum myopias.

………………………………Figure 2 ……………………………………………………………………..

Figure 3 shows the numbers of MHR found if a target did, or did not contain an individual cue. Any target that contained proximal / looming clues (*bdp, dp bp* and *p*) was more effective in producing maximum hyperopic error than those that did not ($\chi^2 = 111.6$, df 1, $p < 0.00001$). A similar comparison between targets that containing disparity cues versus those without disparity showed that MHR was found more often when the target contained disparity cues (χ^2 = 54.1, df 1, p<0.00001) but the effect for proximity was larger than for disparity. The MHR was also more likely to be found in targets that included blur as a cue to depth than those without (χ^2 = 12.83, df 1, p<0.0003)

So despite literature suggesting that minimizing blur cues helps relax accommodation, more MHRs were found with targets containing target detail than those which did not. While all three cues appear significantly associated with helping to relax accommodation, including proximity and disparity in the target appears the most effective in relaxing accommodation.

……………………………Figure 3 ………………………………………………………………………

The data were then divided by age group. We grouped the data into 3 groups - infants, children between 4 & 15 years, who have passed the most active phases of the visual critical period but who would be expected to have the most active accommodation, and adults (Figure 4).

…………………………………Figure 4 …………………………………………………………

There were no significant differences in the distribution of the target which produced the MHR between age groups. The largest age difference was in the *dp* condition, where infants showed proportionally more MHR than children or adults, but even this difference failed to reach significance (χ^2=1.89, df 2, p=0.38).

…………………………………Figure 5 ……………………………………………………………

Figure 5 shows the percentage of MHR found at each target distance with Figure 5a showing the results for all participants and Figure 5b showing the results for only those participants with an MHR greater than +2.00D. When all participants were considered together, the MHR was overwhelmingly found for the most distant target (χ^2=305.2, df 3, p,0.0001). When examined by age group this pattern remained stable (p<0.0001 in all cases). When the higher refractive errors (>+2.00DS) were examined separately, MHR's were found almost equally at the 0.5 and 1D targets (χ^2=0.02, df 1, p=0.88). Although small numbers limited statistical analysis of these hyperopes by age, it was noticeable that of the 19 over 4 yrs of age there appeared to be less association between target distance and MHR (n=7,7,6,3 at 0.5D, 1D, 2D and 3D demand respectively).

We considered whether the significant difference in refraction between fixation at 1m and 2m (as found by Suryakumar & Bobier [21]) was large enough to be clinically meaningful and whether it differed across targets. Mean accommodation at 0.5D demand was significantly less than that at 1D across all target conditions (mean difference 0.23D, 95%CI ± 0.05D (F=159.7, df1,292, p<0.0001) but with no significant interaction with target type (F(7,2044)=1.3,9=0.22)(Fig 6). The variance in these data was remarkably similar. There was a small difference in variance between target type (F(7,4832)=2.41,p=0.019), with the *bdp* target having the smallest variance, but there were no difference between the variances for the 0.5D and 1D target distances (F(7,4838)=2.46,p=0.116), and, overall, these differences in standard error (between ±0.125 and 0.156D) were not large enough to be clinically significant.

…………………………………Figure 6 ………………………………………………………………….

We next considered how MHR compared with other actual and extrapolated measures of refraction we had available in our dataset. In previous studies, we have used the y-intercept of the accommodative response against demand as an estimate of refraction at infinity, and therefore maximum refractive error[33]. In the current study, both measures were available, so we compared y-intercept across targets and with MHR.

As with the MHR counts, the maximally hyperopic intercepts for most individuals were found with the *bdp* and *dp* targets, but even the most hyperopic of the mean y-intercepts (found in the *bdp* condition) is 0.32D less hyperopic than the mean MHR($t=9.94$, df 315, $p<0.00001$).(Figure 7)

…………………………………Figure 7……………………………………………………………………

Finally, we were able to compare MHR and mean spherical equivalent (MSE) derived from cycloplegic retinoscopy on the 59 participants for whom we had recent data (Figure 8).

Mean cycloplegic retinoscopy was only 0.07D (±95%CI of 0.23D) more hyperopic than MHR, with a high correlation co-efficient of 0.93 in this very heterogeneous group. If MHR is compared with the “gold standard” cycloplegic retinoscopy, using a criterion of +2.0 for a marginally clinically significant error, MHR showed a sensitivity of 83.3% and a specificity of 91% in detecting refractive error of >2.00D, comparing very favorably with other methods[29, 30, 34]. If the same comparison is made with y-intercept of accommodation against demand using the *bdp* target (which we found the most accurate of the estimates of refraction)(open data points in Figure 8), sensitivity falls to 45% indicating that some hyperopes would not be detected by using this measure, although specificity remained high at 95%

……………………………………………Figure 8 …………………………………………………

Discussion

The primary motivation for this analysis was to determine how best to estimate refractive error in a group of infants we are studying in our laboratory. In doing so we have also collected data from participants of all ages, using a repeated measures design, the same equipment and lighting conditions and a minimal instruction set. The only experimental manipulation was the target type and position. Our findings, therefore, have wider clinical applications

In general, more cues are better than fewer when assessing maximal hyperopic error. The target most likely to elicit maximum hyperopia or minimum myopia for an individual was not necessarily a blurred target, as might be expected from the common clinical use of fogging lenses to relax accommodation, but one that contained disparity and looming cues as the target was observed receding into the distance. Presence or absence of blur was the least influential of the three near cues we tested, and MHR was just as likely to be found in a target condition that contained detail as in one that did not. Removing blur from the 3-cue condition (*bdp* vs *dp*), or adding blur as a single cue (*b* vs *o* condition) made little difference to the proportions of MHR found between these categories. This intuitively surprising finding differs from the findings of Queiros et al [20]who found that fogging lenses helped relax accommodation. Suryakumar & Bobier[21] found that refraction using a DoG target was more hyperopic than using a LED fixation target. However in their study the different fixation distances used with these two targets make it difficult to differentiate the effect of the target from that of fixation distance. They also state, in an appendix to the paper, that a pilot study failed to find differences between LEDs and high contrast accommodative targets at the same fixation distance. It is possible that the differences in our data may be explained by our DoG target being too blurred or qualitatively different in comparison to the usual +2.00D fogging lens, and so induce some pseudo-myopia[35] rather than relaxing accommodation, but Chiu et al[18]have suggested that the amount of fogging is of relatively little importance, so this explanation seems unlikely.

Although some studies have looked at the best target and testing distance to help relax accommodation[20, 21], none have looked systematically at target type and distance in the same participants. Our findings largely support those of others[21] in that distant targets relax accommodation more than nearer ones, but we suggest that additional hyperopia can be revealed in many individuals by using a binocular, receding target.

It is not surprising that the most distant target produced most MHRs, and we found that the difference in refraction between the 2m and 1m targets remained relatively constant across targets. Suryakumar & Bobier[21] also found that the farthest distant targets relax accommodation the most, but also found that responses were less variable at these greater fixation distances. We found non-significant differences in the variance between the two most distant fixation targets in any of the cue conditions. In participants with refraction < + 2.0D, MHR occurred less reliably at the 2m target, possibly suggesting more variability or less sensitivity to target distance in these individuals, which would benefit from further study.

Our results are supported by our previous research. We have reported that in normal, emmetropic, naïve adults, disparity is the primary cue for both vergence and accommodation to near targets[22]. Reducing disparity, therefore, may well help relax accommodation as well as it drives it, increasing the number of MHRs found (e.g. the large difference between *bdp* vs *bp* conditions) although alone (the *d* vs *o* condition) disparity seems to have little effect. Fukuda et al [36] found that accommodation velocity was also greater in binocular conditions, so giving additional support to the view that disparity helps accommodation accuracy more than does blur.

The strong effect of proximity / looming was less expected. Like disparity, it seems to have a weak effect as a single cue (*p* vs *o* condition), but in combination with disparity it was the cue which predicted the highest proportion of MHRs. We have reported that proximity is an extremely weak cue in comparison to disparity[22] in driving both vergence and accommodation to near targets in naïve adults (as opposed to those with some knowledge of vision experiments as studied by others[37]). Hung et al [38], also suggested that proximity played a small part under naturalistic conditions, but here, in combination with disparity in a very naturalistic setting, the "negative looming" of the moving target seems to help in relaxing accommodation in the distance.

If a correction is made for the systematic underestimation of accommodation by the PlusoptiX SO4 in our laboratory, MHR also agreed extremely well with cycloplegic refraction. When analyzed by age group and refractive error, we found no systematic age differences, so our findings may be useful not only in our laboratory, but also in clinical settings.

In the past we have used y-intercept of accommodation response slopes as a proxy measure of refraction in our laboratory [33, 39, 40], but because of the variance in some of the infant data, where responses may be more erratic, and the flatter response slopes in impoverished cue conditions, we now believe that MHR found at any time within a session is a more reliable estimate of true refraction in our laboratory, as demonstrated by the close correlation with cycloplegic refraction (with narrow confidence limits of less than ±0.25D). MHR has a much greater sensitivity in detecting significant hyperopia than when using y-intercept. However, the scope for statistical analysis of our categorical data was somewhat limited and so further corroborative research may be necessary.

A further area for future research is to consider groups that would not be expected to have normal disparity detection mechanisms e.g. the very youngest infants under 12-16 weeks, before stereopsis has fully developed [41], and strabismic older children with constant suppression. Our numbers were too small here, and we had no participants with total absence of binocularity, but we would be predict that disparity cues would be less influential in these individuals and may differ depending on the strength of binocularity or suppression. Such groups also have a high prevalence of refractive error, so they may rely even more heavily on proximal cues.

These data have some wider clinical implications. In terms of refractive errors, while myopia may be more of a problem with older children, hyperopia is arguably the most pressing condition for younger children. As well as reducing visual acuity, hyperopia is co-morbid with strabismus, amblyopia and failure at school [42, 43] and needs more prompt referral to avoid amblyopia and loss of binocularity. It may, however, remain undetected or underestimated if accommodation is exerted at the time of testing. Picking a target that increases the chances of detecting maximum hyperopia is clearly preferable in young children.

In the absence of cycloplegia, there are many optometric techniques available to reveal maximum hyperopia during a detailed subjective refraction within a comprehensive and skilled examination. We did not assess the sustained responses that are necessary for such testing and so our findings may not necessarily transfer to these situations. Autorefraction screening situations, however, often use unskilled personnel in a "one off" event and using a pass/fail criterion. We have found that changing the target increases the chances of revealing a maximum hyperopia which is very close to that of a cycloplegic refraction. Our findings appear to be consistent across all the participants tested, so may be useful in developing techniques to reduce false positives in the case of myopia and false negatives in the case of hyperopia. No one target always produces MHR, and MHR can be found with any target, so non-cycloplegic autorefraction still risks missing some hyperopic children, but a binocular receding target, whether blurred or clear, increases the probability of maximum accommodative relaxation, so increasing sensitivity & specificity in detecting hyperopia. Adding a looming component to a binocular fixation target may also aid subjective refraction in office situations and may be a fruitful topic for future clinical research.

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References

1.Ehrlich D, Braddick O, Atkinson J, Anker S, Weeks F, Hartley T, et al. Infant Emmetropization: Longitudinal changes in refraction components from nine to twenty months of age. Optom Vision Sci. 1997;74:822-43.

2.Gwiazda J, Thorn F, Bauer J, Held R. Emmetropisation and the progression of manifest refraction in children followed from infancy to puberty. Clin Vis Sci. 1993;8:337-44.

3.Iuorno JD, Grant WD, Noel LP. Clinical comparison of the Welch Allyn SureSight handheld autorefractor versus cycloplegic autorefraction and retinoscopic refraction. J Aapos. 2004;8(2):123-7.

4.Buchner TF, Schnorbus U, Grenzebach UH, Busse H. Examination of preschool children for ametropia: first experiences using a new hand-held autorefractor. Strabismus. 2004; 12(2):111-7.

5.Dahlmann-Noor AH, Comyn O, Kostakis V, Misra A, Gupta N, Heath J, et al. Plusoptix Vision Screener: The accuracy and repeatability of refractive measurements using a new autorefractor. Br J Ophthalmol. 2009; 93(3): 346-9.

6.Dahlmann-Noor AH, Vrotsou K, Kostakis V, Brown J, Heath J, Iron A, et al. Vision screening in children by Plusoptix Vision Screener compared with gold standard orthoptic assessment. Br J Ophthalmol. 2009; 93(3): 342-5.

7.Kaakinen K, Ranta-Kemppainen L. Screening of infants for strabismus and refractive errors with two-flash photorefraction with and without cycloplegia. Acta Ophthalmol (Copenh). 1986; 64(5):578-82.

8.Ghose S, Nayak BK, Singh JP. Critical evaluation of the NR-1000F Auto Refractometer. Br J Ophthalmol. 1986;70(3):221-6.

9.Sjostrand J, Abrahamsson M. Can we identify risk groups for the development of amblyopia and strabismus? (in German). Klin Monatsbl Augenheilkd. 1996; 208(1):23-6.

10.Atkinson J, Braddick O, Robier B, Anker S, Ehrlich D, King J, et al. Two infant vision screening programmes: prediction and prevention of strabismus and amblyopia from photo- and videorefractive screening. Eye. 1996;10((Pt 2)(10)):189-98.

11.Atkinson J, Braddick O. Infant precursors of later visual disorders: Correlation or causality. 20th Minnesota Symposium on Child Psychology. A.Yonas (Ed) Lawrence Erlbaum Associates, Hillsdale,NJ 1988;20:35-65.

12.Williams C, Northstone K, Howard M, Harvey I, Harrad RA, Sparrow JM. Prevalence and risk factors for common vision problems in children: data from the ALSPAC study. Br J Ophthalmol. 2008, 2008;92(7):959-64.

13.Williams WR, Latif AH, Hannington L, Watkins DR. Hyperopia and educational attainment in a primary school cohort. Arch Dis Child. 2005;90(2):150-3.

14.Shankar S, Evans MA, Bobier WR. Hyperopia and emergent literacy of young children: pilot study. Optom Vis Sci. 2007;84(11):1031-8.

15.Atkinson J, Nardini M, Anker S, Braddick O, Hughes C, Rae S. Refractive errors in infancy predict reduced performance on the movement assessment battery for children at 3 1/2 and 5 1/2 years. Dev Med Child Neurol. 2005;47(4):243-51.

16.Owens D, Liebowitz H. Accommodation, convergence, and distance perception in low illumination. Am J Optom Physiol Opt. 1980;57(9):540-50.

17.Kotulak J, Schor C. The effects of optical vergence, contrast, and luminance on the accommodative response to spatially bandpass filtered targets [published erratum appears in Vision Res 1988;27(10):361]. Vision Res. 1987;27(10):1797-806.

18.Chiu NN, Rosenfield M, Wong LC. Effect of contralateral fog during refractive error assessment. J Am Optom Assoc. 1997;68(5):305-8.

19.Ward PA, Charman WN. An objective assessment of the effect of fogging on accommodation. Am J Optom Physiol Opt. 1987;64(10):762-7.

20.Queiros A, Gonzalez-Meijome J, Jorge J. Influence of fogging lenses and cycloplegia on open-field automatic refraction. Ophthalmic Physiol Opt. 2008;28(4):387-92.

21.Suryakumar R, Bobier WR. The manifestation of noncycloplegic refractive state in pre-school children is dependent on autorefractor design. Optom Vis Sci. 2003;80(8):578-86.

22.Horwood A, Riddell P. The use of cues to convergence and accommodation in naïve, uninstructed participants. Vision Research. 2008;48(15):1613-24.

23.Bharadwaj SR, Candy TR. Cues for the control of ocular accommodation and vergence during postnatal human development. Journal of Vision., 2008;8(16):1-16.

24.Fincham E, Walton J. The reciprocal actions of accommodation and vergence. J Physiol. 1957;137:488-508.

25.Judge S. How is binocularity maintained during convergence and divergence? Eye. 1996;10((Pt 2)):172-6.

26.Stark L. Normal and abnormal vergence. In: C.Schor, K.Cuiffreda, editors. Vergence Eye Movments. Woburn,MA: Butterworth; 1983. pp. 3-14.

27.Currie D, Manny R. The development of accommodation. Vision Res. 1997;37(11):1525-33.

28.Kennedy R, Sheps S. A comparison of photoscreening techniques for amblyogenic factors in children. Can J Ophthalmol. 1989;24:259-64.

29.Enzenauer RW. The Efficacy of Photoscreening for Amblyopiagenic Factors in a High Risk Population. Binocular Vision And Strabismus Quarterly. 2003;18(4):233-41.

30.Hamer R, Norcia A, Day S, Haegerstrom-Portnoy G, Lewis D, Hsu-Winges C. Comparison of on- and off-axis photorefraction with cycloplegic retinoscopy in infants. J Pediatric Ophthalmol & Strab. 1992;29:232-9.

31.Erdurmus M, Yagci R, Karadag R, Durmus M. A comparison of photorefraction and retinoscopy in children. J AAPOS. 2007 ;11(6):606-11.

32.Harb E, Thorn F, Troilo D. Characteristics of accommodative behavior during sustained reading in emmetropes and myopes. Vision Res. 2006;46(16):2581-92.

33.Turner JE, Horwood AM, Houston SM, Riddell PM. Development of the response AC/A ratio over the first year of life. Vision Res. 2002;42(22):2521-32.

34.Cordonnier M, Dramaix M. Screening for abnormal levels of hyperopia in children: a non-cycloplegic method with a hand held refractor. Br J Ophthalmol. 1998;82(11):1260-4.

35.Jones R. Physiological pseudomyopia. Optom Vis Sci. 1990;67(8):610-6.

36.Fukuda T, Kanada K, Saito S. An ergonomic evaluation of lens accommodation related to visual circumstances. Ergonomics. 1990;33(6):811-31.

37.Rosenfield M, Ciuffreda KJ, Hung GK. The linearity of proximally induced accommodation and vergence. Invest Ophthalmol Vis Sci. 1991 ;32(11):2985-91.

38.Hung G, Ciuffreda K, Rosenfield M. Proximal contributions to a linear static model of accommodation and vergence. Ophthalmic Physiol Opt. 1996;16:31-41.

39.Horwood A. Too much or too little: neonatal ocular misalignment frequency can predict later abnormality. Brit J Ophthalmol. 2003;87(9):1142-5.

40.Horwood A, Riddell P. Can misalignments in typical infants be used as a model for infantile esotropia? Invest Ophthalmol Vis Sci. 2004;45(2):714-20.

41.Birch E, Gwiazda J, Held R. Stereoacity development for crossed and uncrossed disparities in human infants. Vision Res. 1982;22:507-13.

42.Atkinson J, Braddick O, Nardini M, Anker S. Infant hyperopia: detection, distribution, changes and correlates-outcomes from the Cambridge infant screening programs. Optom Vis Sci. 2007 ;84(2):84-96.

43.Roch-Levecq A-C, Brody B, Thomas R, Brown S. Ametropia, Preschoolers' Cognitive Abilities and Effects of Spectacle Correction at 6-Month Follow-Up. Invest Ophth Vis Sci. 2008;49:e-abstract 1427.

Figure Legends

Figure 1

Remote haploscopic videorefractor. A. Motorised beam. B. Target monitor. C. Upper concave mirror. D. Lower concave mirror. E. Hot mirror. F. Image of participant's eye where occlusion takes place. G. PlusoptiX SO4 PowerRef II. H. Headrest J. Raisable black cloth screen.

Figure 2

Percentages of MHR found for each target condition

Figure 3

Distribution of MHR according to whether an individual cue was present or absent in the target. Pale bars = cue present, dark bars = cue absent. p = proximity/looming(*bdp,bp,dp,p* targets vs. *bd,b,d,o*), d = disparity (*bdp,bd,dp,d* targets vs. *bp,b,p,o*), b = blur (*bdp,bd,bp,b* vs. *dp,d,p,o).* All differences between present and absent cues significant.

Figure 4.

Distribution of MHR across age groups and target. There were no significant differences between age groups.

Figure 5

Target distances where MHR found (%). a) all participants (n = 316) b) hyperopes ≥2.00D only (n = 55)

Figure 6

Accommodation responses at 2m (0.5D) and 1m (1D) fixation distances. NB. Includes a wide range of refractive errors and ages. Note similar size standard error bars in every cue condition.

Figure7.

y-intercepts of mean accommodation (response against target demand) by target type (dotted line = mean y- intercept across all targets). Minimum (most hyperopic) y-intercepts also found in the bdp and dp conditions, but always less hyperopic than mean MHR (dashed line) in the same particpants.

Figure 8.

MHR and y-intercept of accommodation (*bdp* target) against demand compared with refraction obtained from cycloplegic refraction (mean spherical equivalent). Filled points and solid fit line = MHR vs cyclo. Open points and dotted fit line = y-intercept vs cyclo.

Figure

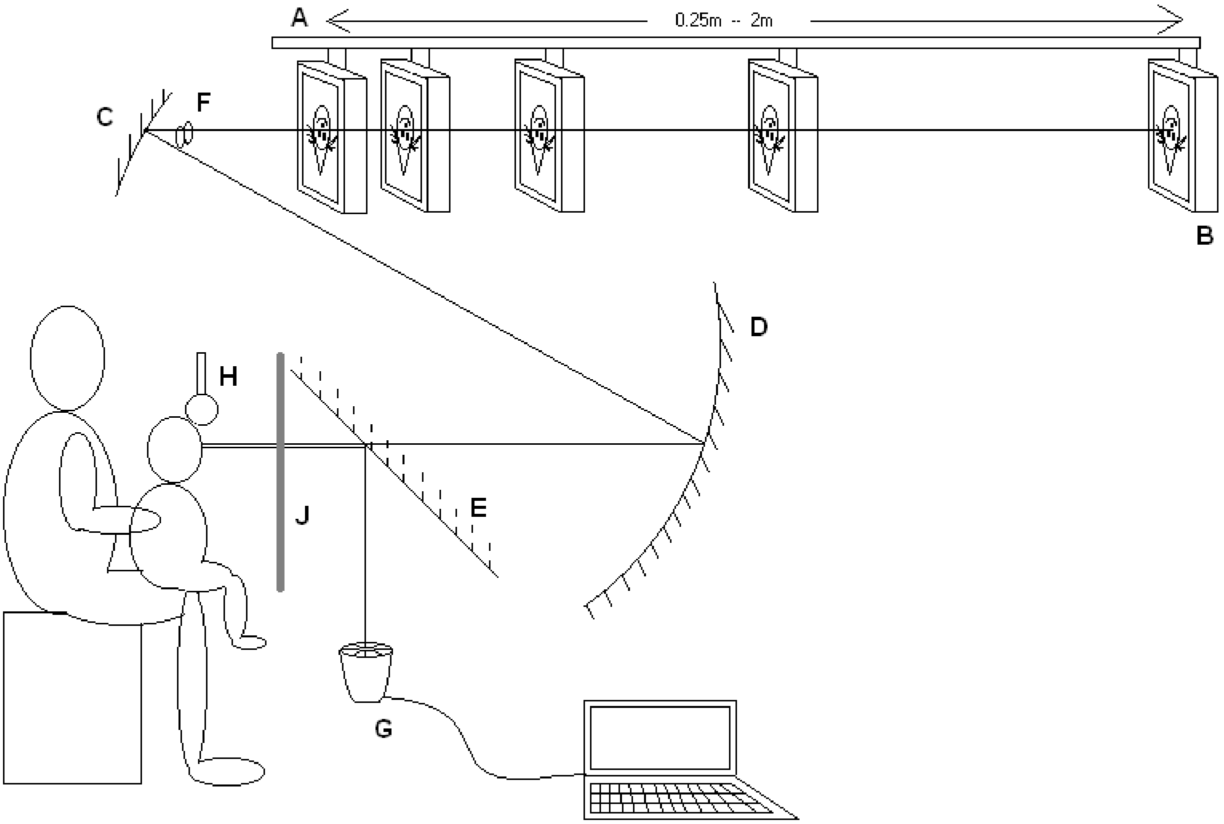

Figure 1

Figure

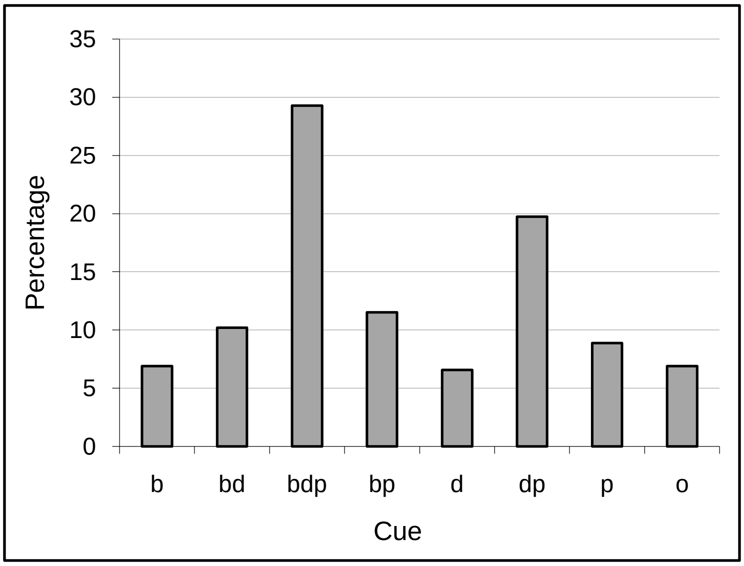

Figure 2

Figure

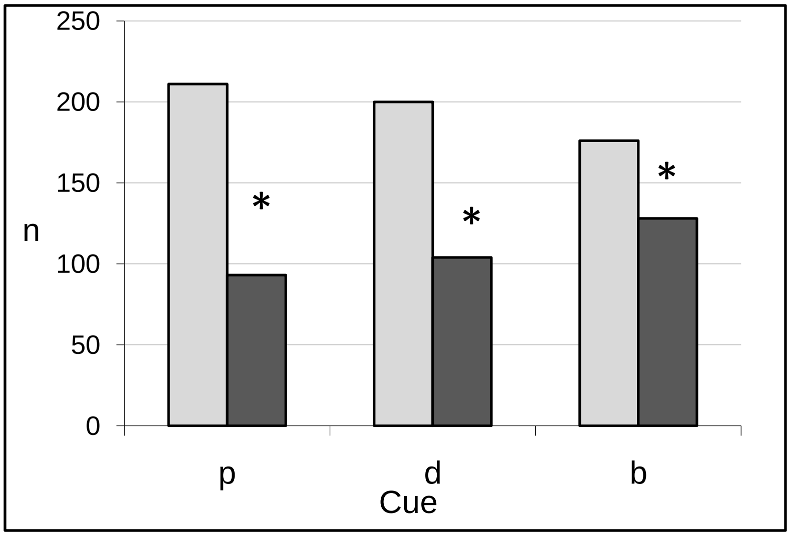

Figure 3

Figure

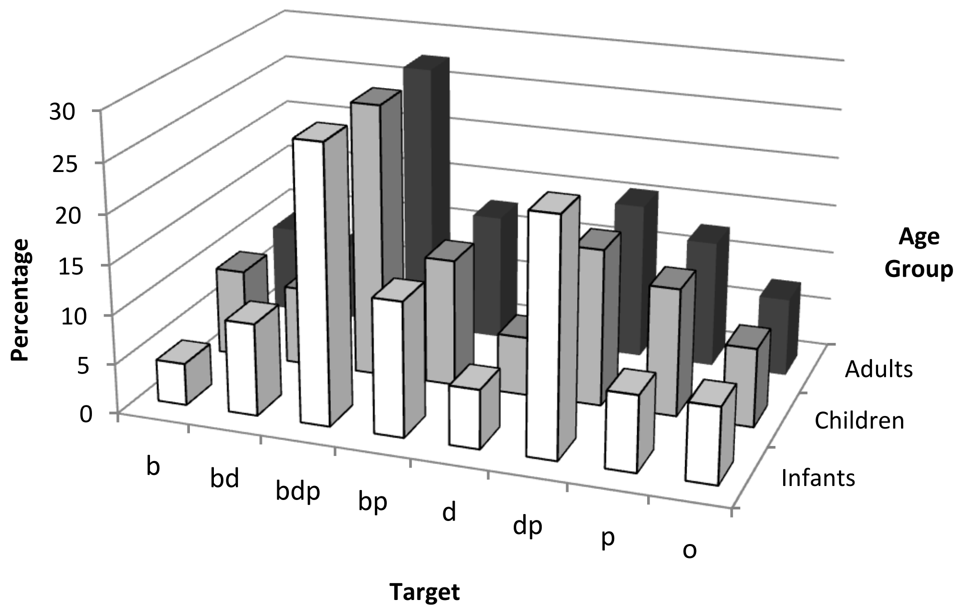

Figure 4

Figure

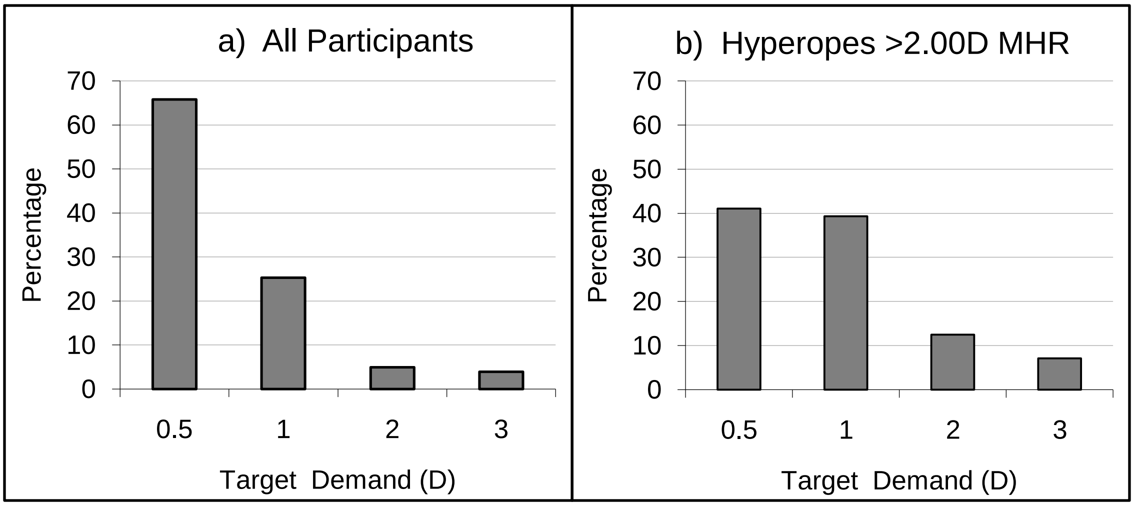

Figure 5

Figure

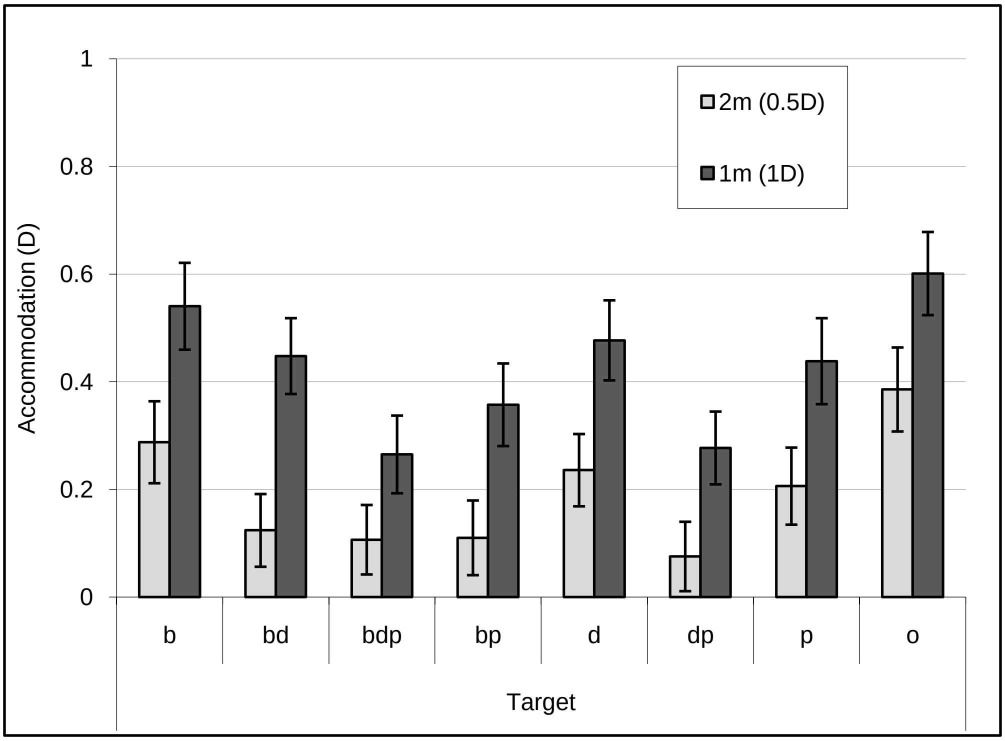

Figure 6

Figure

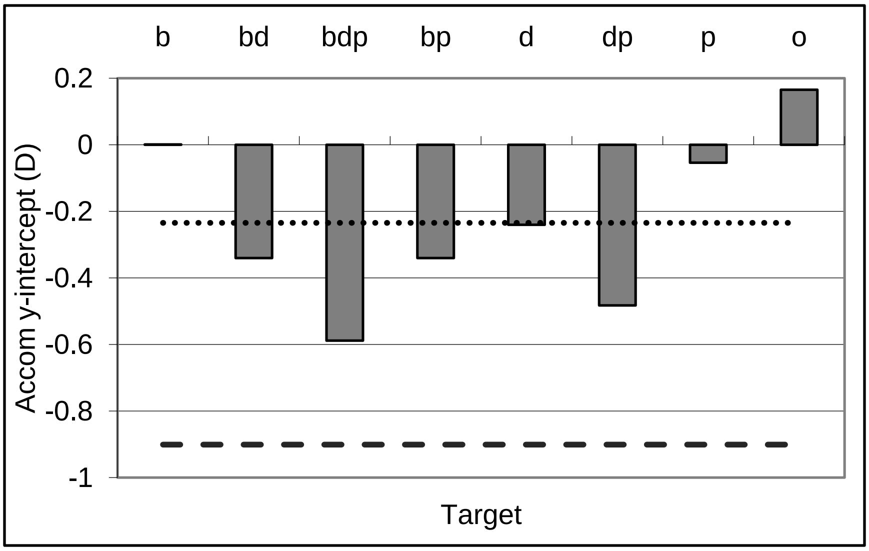

Figure 7

Figure

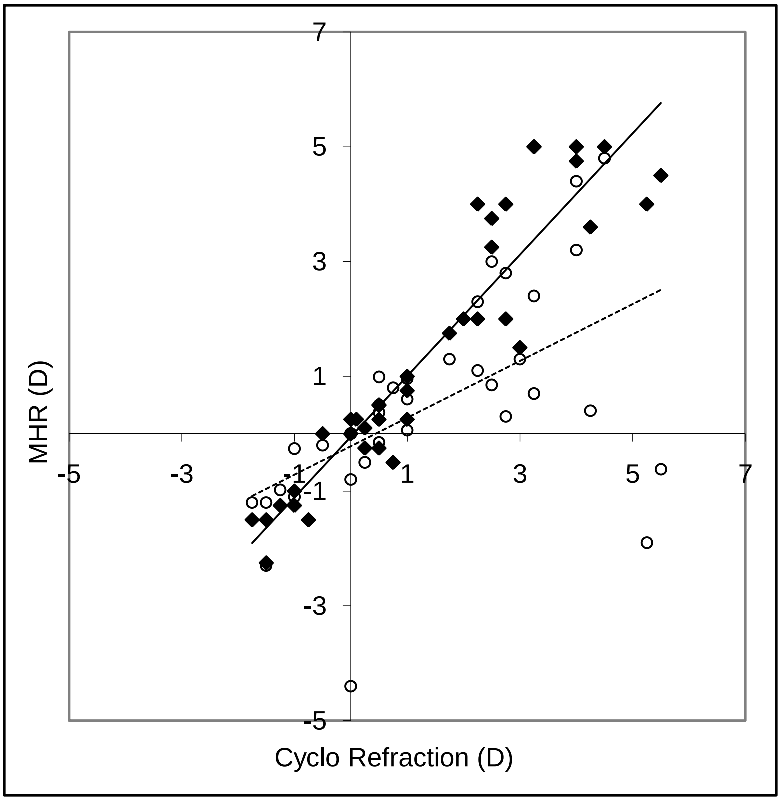

Figure 8